Clean Coal Technology Options: A Primer on Western Fuel Markets, Pulverized Coal Power Plants, and Combustion and Gasification–Based Advanced Coal Power Plants

Stu Dalton (sdalton@epri.com)
Director, Generation
Electric Power Research Institute

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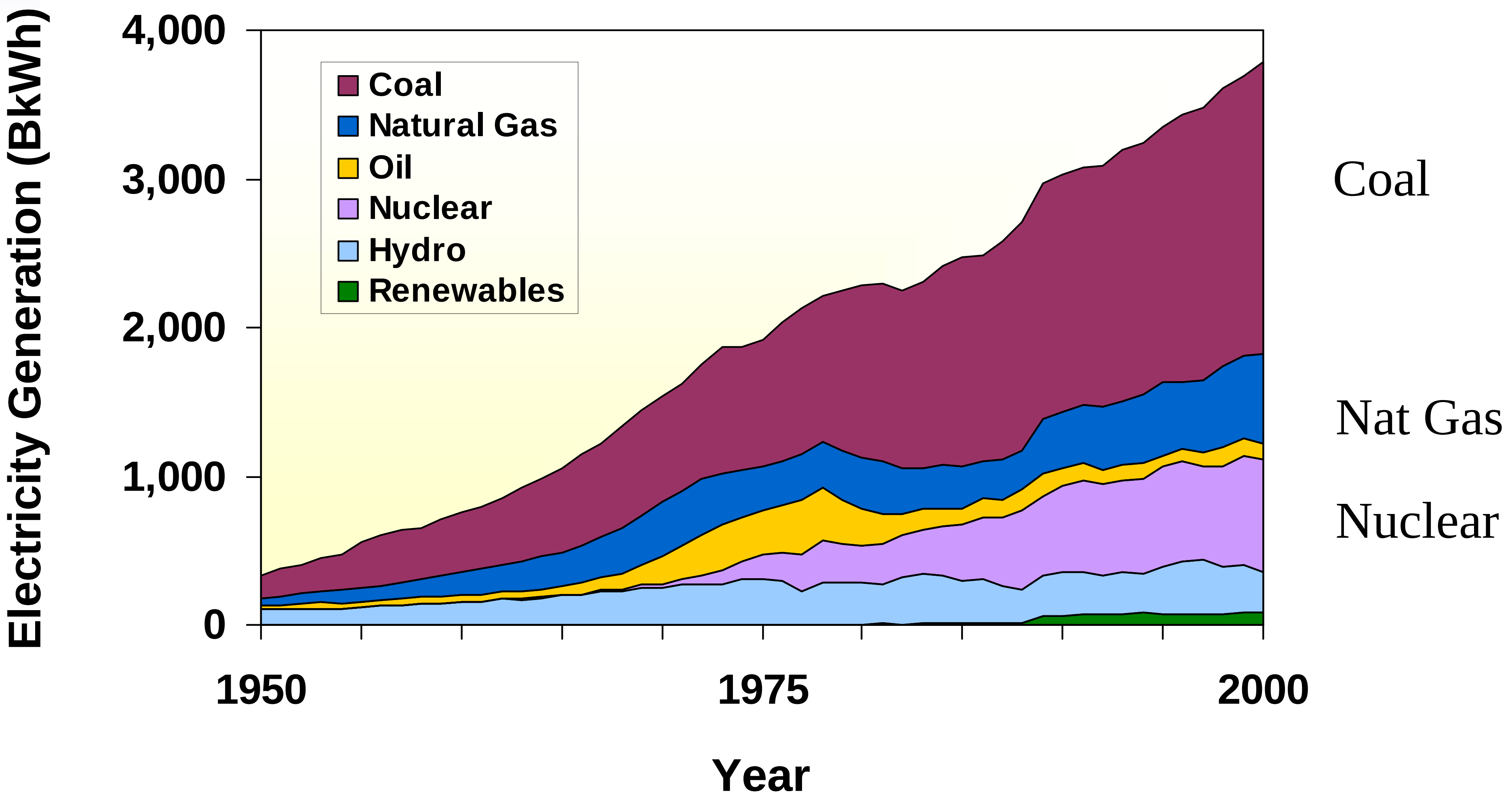
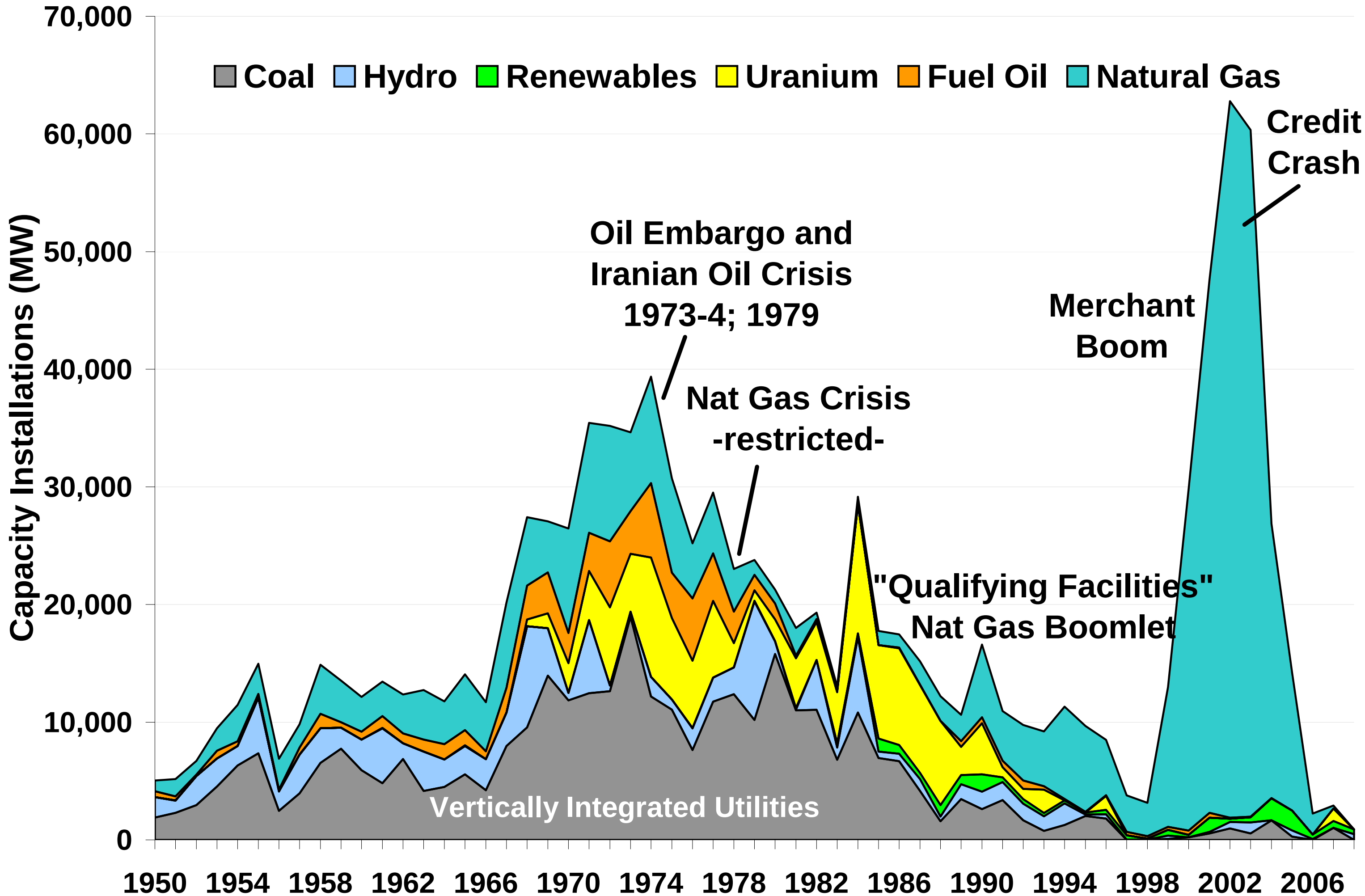
U.S. Generation by Fuel



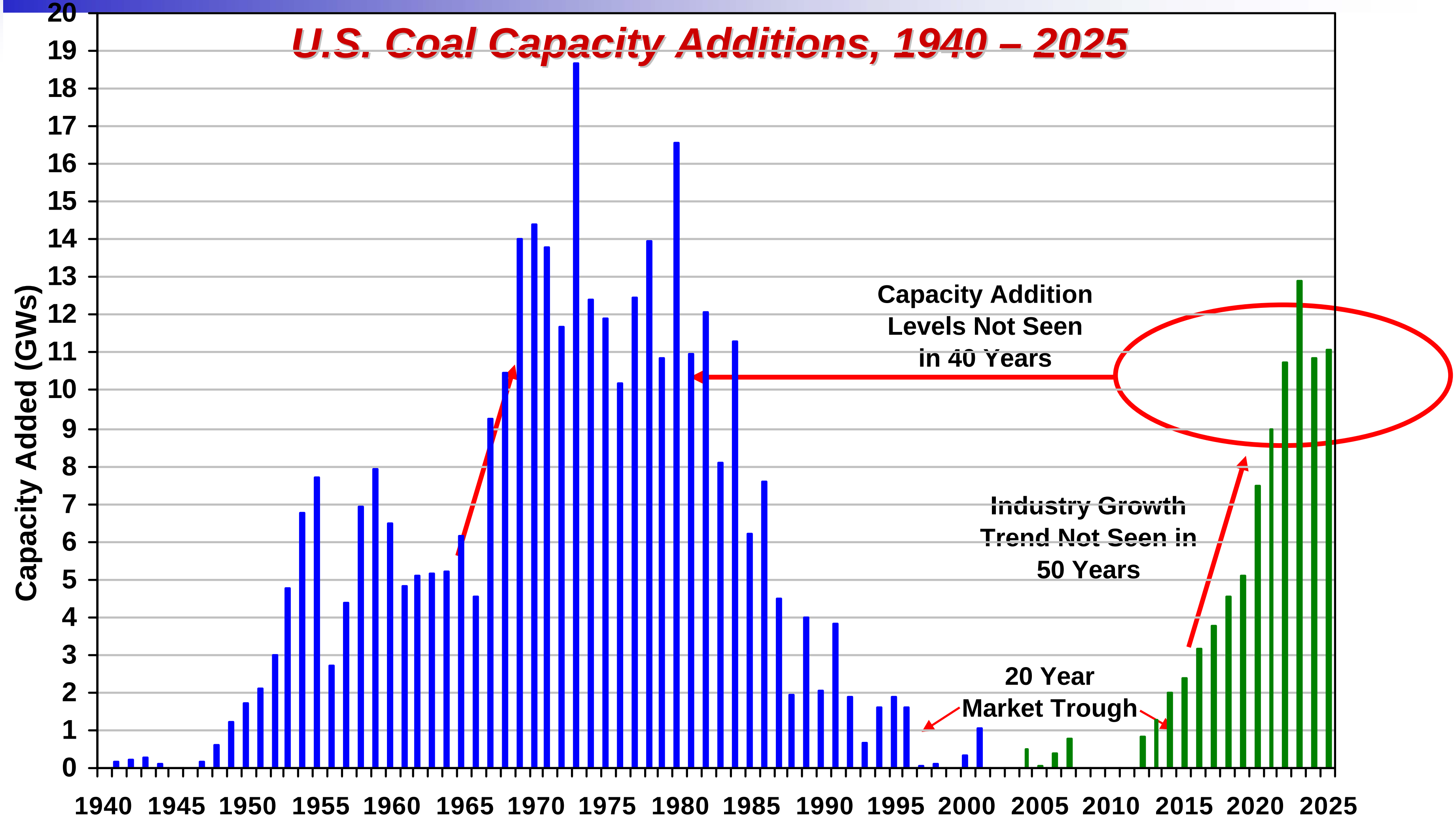
Source: DOE/EIA

Generation Capacity Additions



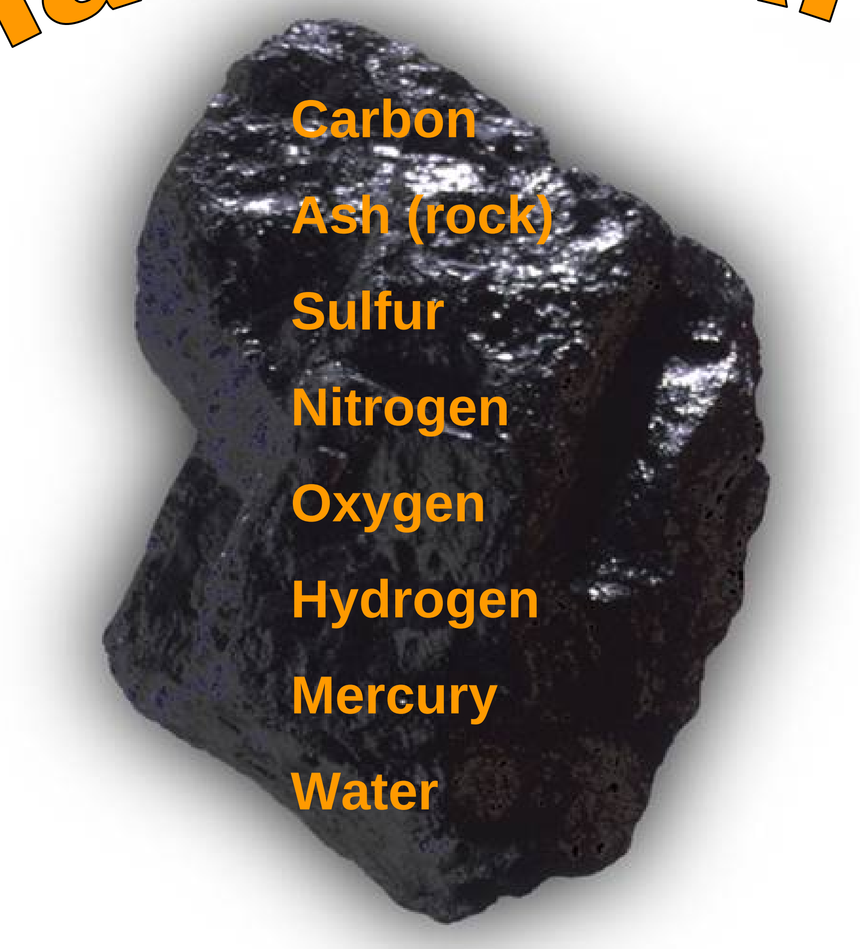
By permission: Global Energy Decisions and the Global Energy Reference Case March 2004; adapted from Oct-04 *Public Utilities Fortnightly.*

U.S. Forecasts Largest Coal Generation Capacity Installation in 40 Years



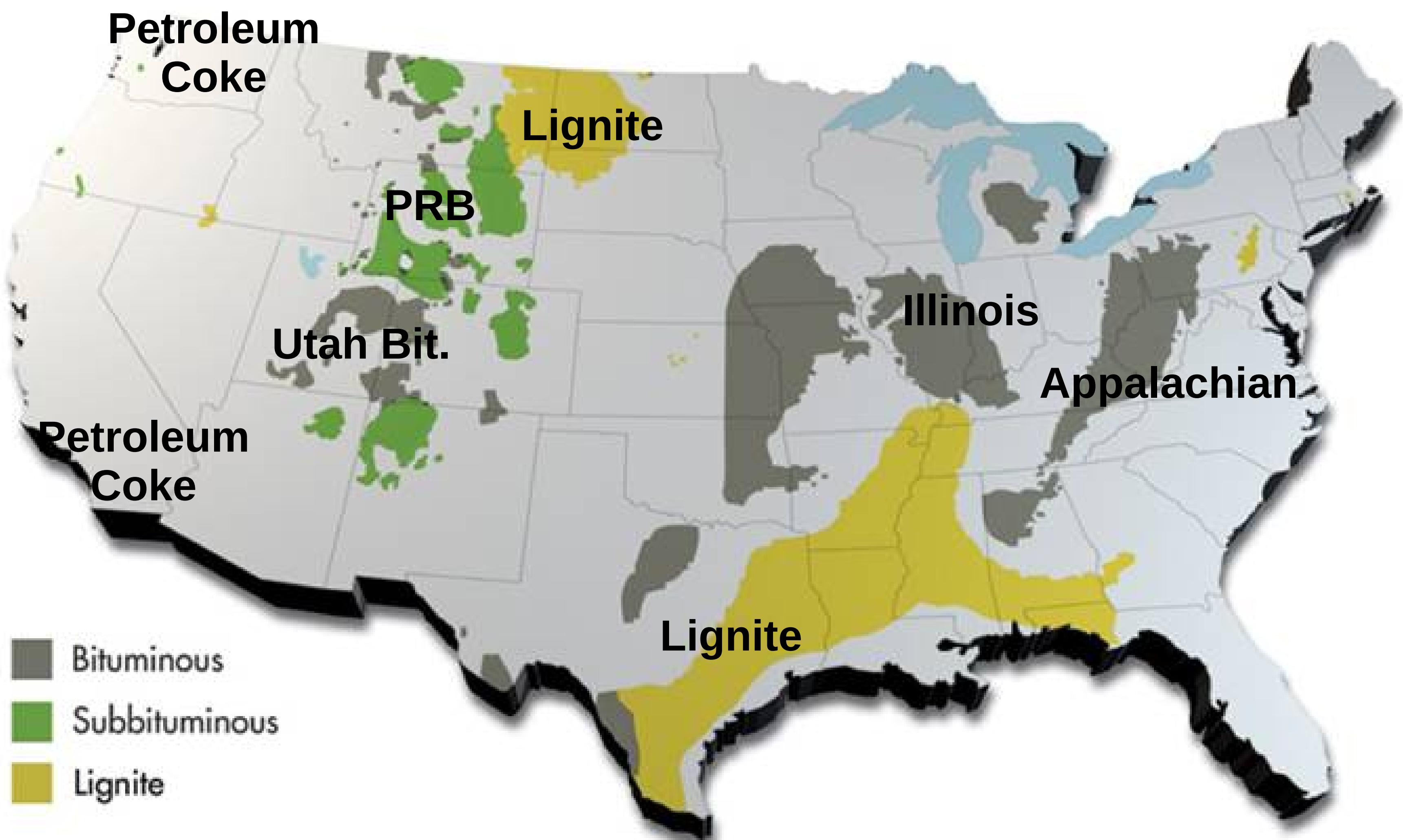
Source: U.S. Department of Energy NETL & Annual Energy Outlook 2005.

What Is Coal???



- Carbon
- Ash (rock)
- Sulfur
- Nitrogen
- Oxygen
- Hydrogen
- Mercury
- Water

U.S. Coal Types and Basins (and other Western solid fuel)



Typical U.S. Coal Analyses (Coal Properties Differ Markedly)

	Pittsburgh #8	Illinois #6	Wyoming PRB	Texas Lignite
Ultimate Analysis				
Moisture	5.2	12.2	30.24	33.03
Carbon	73.8	61.0	48.18	35.04
Hydrogen	4.9	4.25	3.31	2.68
Nitrogen	1.4	1.25	0.70	0.77
Chlorine	0.07	0.07	0.01	0.09
Sulfur	2.13	3.28	0.37	1.16
Oxygen	5.4	6.95	11.87	11.31
Ash	7.1	11.0	5.32	15.92
Higher Heating Value as received (Btu/lb)	13,260	10,982	8,340	6,010

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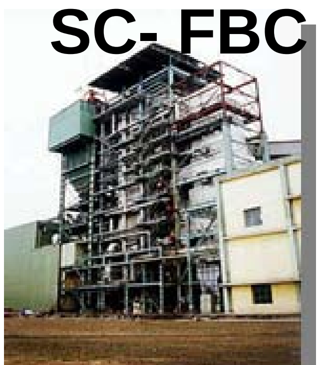
Types of Coal Generation

- **Pulverized coal** (PC): Finely ground coal is burned to make steam and then flue gases are cleaned up; there are more than 1000 such "conventional coal" plants in the U.S.
- **Very high-temperature versions of PC** employ supercritical (SC) steam, and even higher use ultra-supercritical (USC)
- **Circulating fluidized-bed combustion** (CFBC or FBC): Larger coal pieces are "fluidized" by combustion air and entrained with a "sorbent" such as limestone to remove SO_2
- **Gasification** of coal involves reaction with oxygen and heat/ steam to produce a "synthesis gas" containing CO, hydrogen, and methane. The gas is cleaned and then burned in gas turbine with the exhaust heat used to make steam; such plants are "integrated gasification combined cycle" (IGCC).

What Is “Clean Coal?”

- Even modern conventional coal plants are much cleaner than prior designs, but most people refer to designs meeting very stringent emission regulations as “clean coal”
- Coal-based IGCC plants have very low SO_2 and mercury emissions and are almost as clean as natural gas plants
- DOE, EPRI, and the Coal Utilization Research Council have defined clean coal plant performance and emission goals for 2010 and 2020 (see Roadmap at www.coal.org)

Regional U.S. Coal Differences Favor Multiple Advanced Coal Options



- **IGCC works best with "high-rank" bituminous coals or low-rank coal plus petroleum coke (today's economics do not favor IGCC, but it has lower emissions)**
- **New IGCC designs may be better for low-rank coal and may be cheaper, but these designs are still developmental**
- **Waste coals and biomass may be best in fluidized-bed combustion (FBC) units, but supercritical steam conditions are unproven**
- **Most U.S. plans are for new "conventional" pulverized coal due to lower fuel costs; in Europe and Japan, where fuel costs are high, ultra-supercritical (USC) designs are favored**

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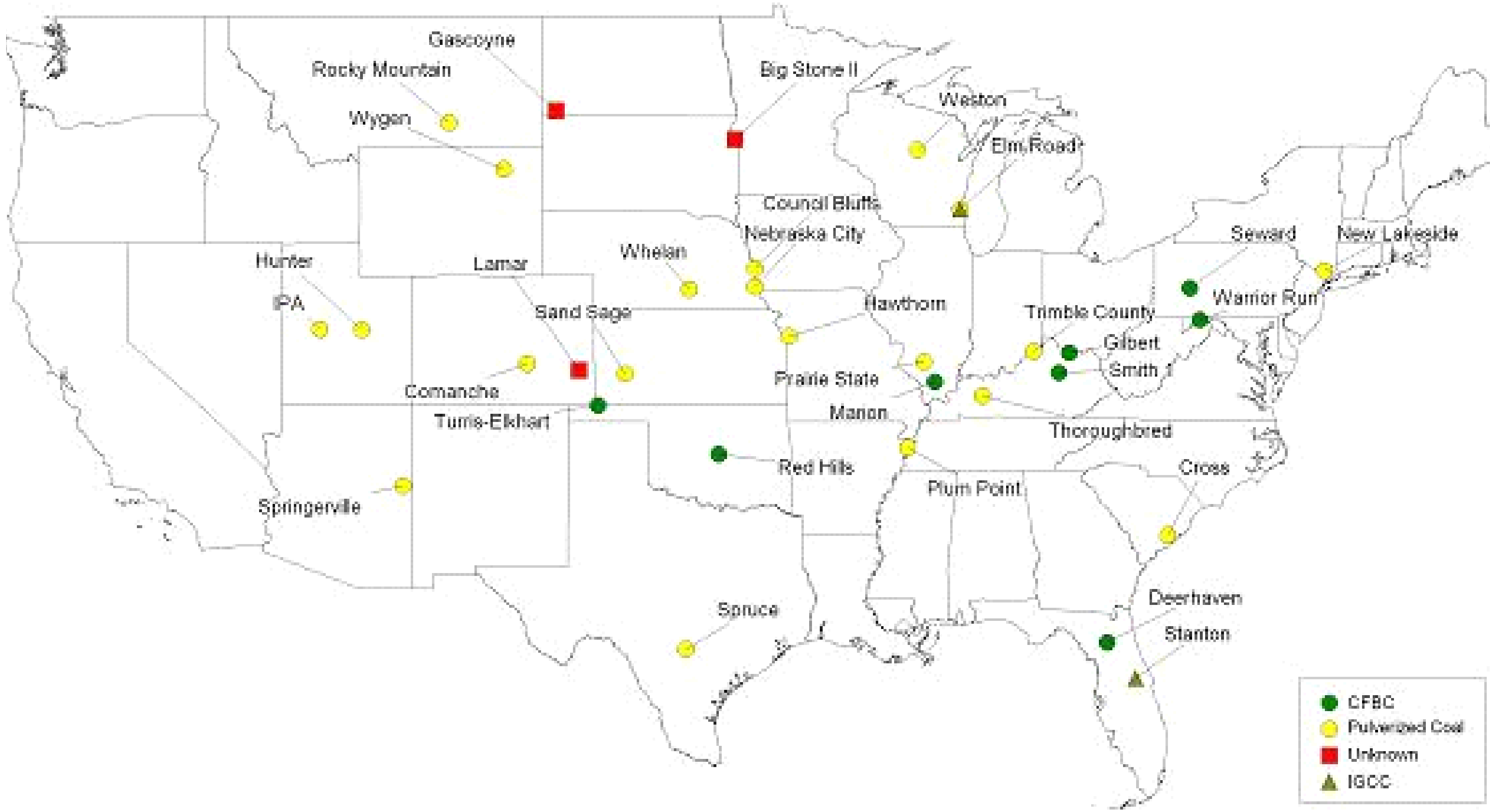
Potential Coal 2005–2012



Ref.: EPRI P67 Newsletter on New Power Plants, March-April 2005

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“Cleaning” a Pulverized Coal Plant

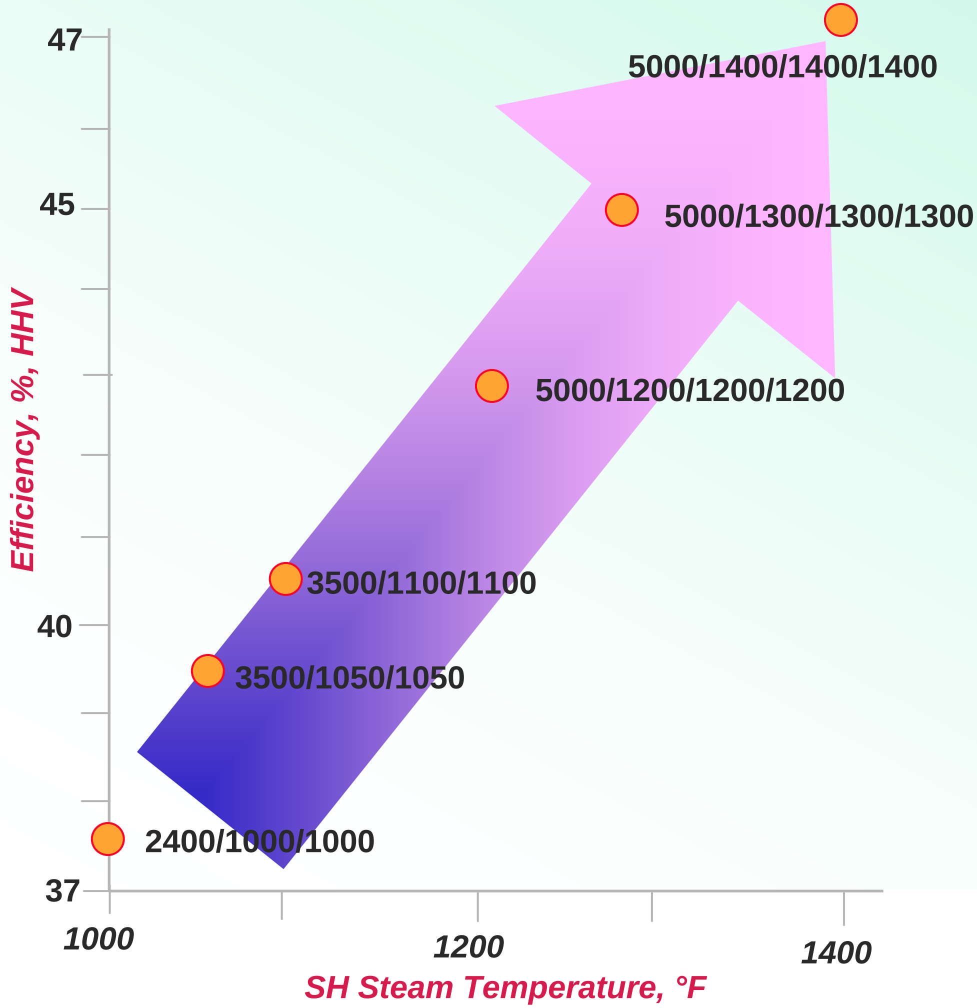
Fuel (low S) | Burners (Low NOx) | Catalyst for NOx | Precipitator (Particulate) | Scrubber (SO2)

- Fuel selection is critical for sulfur and other contaminants
- Burners on new units emit less NO_X via controlling fuel air mixing and temperature
- Billions being invested on selective catalytic reduction (SCR…NO_X + NH_3 going to N_2 + H_2O)—very low NO_X possible from combustion and SCR
- High-efficiency (>99.5%) electrostatic precipitators (ESP) or fabric filters (baghouses) remove dust (fly ash)
- Flue gas desulfurization (scrubbers) react limestone with SO_2 giving gypsum; new designs offer >95% removal, 99% is possible

Subcritical vs. Supercritical and Ultra-Supercritical Coal

- These are all terms for variations of boilers that make steam to run a steam turbine
- Supercritical steam is above the supercritical point of water (3208 psi). Ultra-supercritical is jargon for higher efficiency steam above ~1050°F
- Hundreds of supercritical boilers exist, including some in California (gas-fired); most are larger units
- In the U.S., low fuel price has made the boiler choice less uniform; in China, Japan, and Europe, supercritical and ultrasupercritical designs dominate new units
- Newest units are >40% efficient and have low emissions vs. fleet average of ~32% for existing coal

Ultrasupercritical PC Plants



- **European and Japanese USC PC Experience Base**
  - 600°C (1112°F) high availability, good load following
  - Baseline S-O-A for a new coal-fired plant
- **In Development:**
  - European Advanced 700°C PC (1292°F)
  - *DOE EIO/EPRI 760°C (1400°F) boiler materials program*

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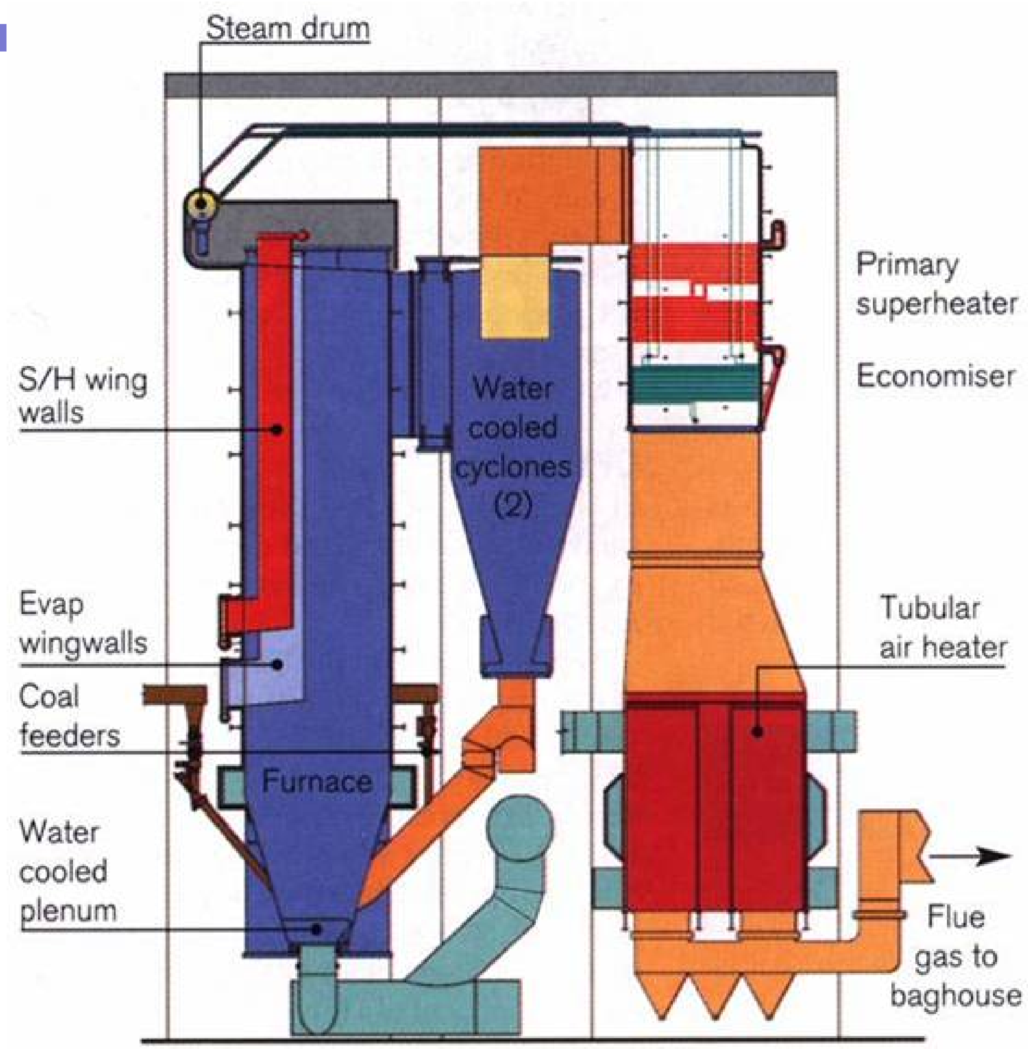
PC Plants Status, Markets, and Vendors

- 310 GW in U.S.; mostly built 25–50 years ago. Majority are subcritical, but there are 150 supercritical plants at steam temperatures <1050°F and up to 1300 MW in size.
- For new U.S. PC plants, subcritical or modest supercritical designs are being selected
- Uncertainty and concern about potential regulation of CO_2
- Main vendors in U.S. (and worldwide) are Babcock & Wilcox, Alstom, Foster Wheeler, Hitachi, Babcock Hitachi, Mitsubishi, IHI, and Mitsui Babcock

Atmospheric Fluidized-Bed Combustion (AFBC): Comparison to PC

- Combustion occurs at 1600°F, well below the 2500°F of a PC boiler
  - Reduced inherent NO_x
  - Less ash deposition and fouling
  - In-situ SO_2 capture with limestone
  - Able to handle a wider range of fuels
  - Fuel size up to ½ inch
- Many similarities to PC boiler
  - Water-wall construction, convection pass, air heaters, baghouse/ESP, ash handling equipment

Circulating AFBC Installed at Marion, Illinois



115 MW net – Photo Source Alstom

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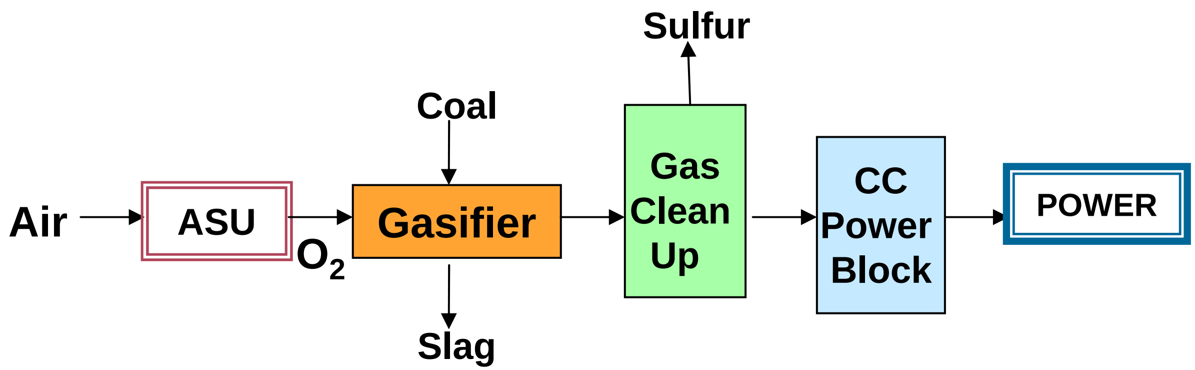
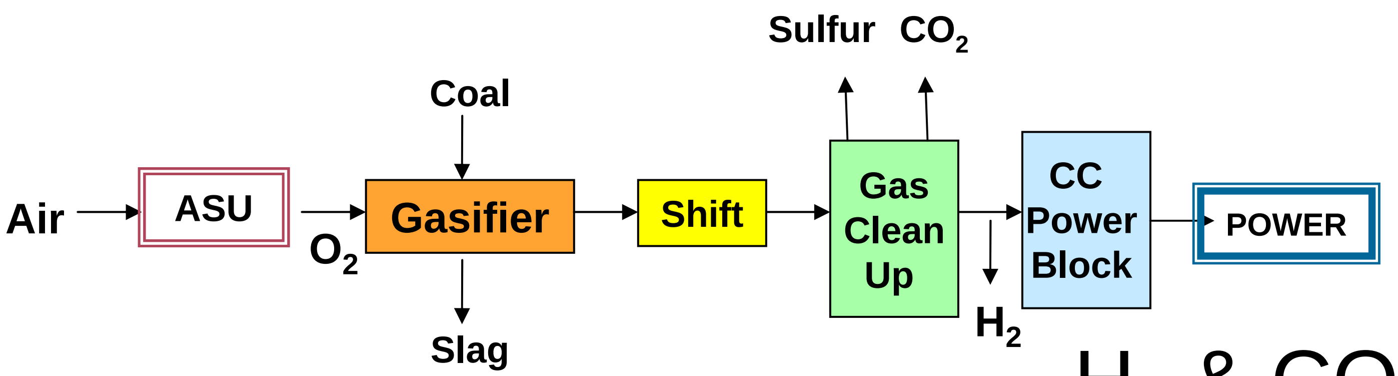
FBC Plant Status, Markets, and Vendors

- Circulating FBC dominates. Currently **maximum size of 300 MW** and subcritical steam. First 440-MW supercritical unit ordered for Poland.
- ~10 GW installed in U.S. Market niche for poor quality and variable quality coals, petroleum coke, and biomass/ “opportunity fuels”
- Pressurized FBC developed up to 350 MW in Japan, but does not compete with 1-GW PC plants. Future commercial application unlikely.
- Main vendors: Alstom (U.S., Europe), Foster Wheeler (U.S., Finland), Kvaerner (U.S., Finland), and Lurgi (Germany)

IGCC with and without CO_2 Removal



IGCC



H_2 & CO_2
(e.g., FutureGen)

Today's Existing Coal-Based IGCC Plants

Puertollano (Spain)

Wabash (Indiana)

Polk (Florida)

Buggenum (Netherlands)

IGCC Environmental Control

- Sulfur is removed from syngas at >99.5%
- NO_X emissions are controlled similar to NG; SCR possible
- Particulates are removed from the syngas by filters and water wash prior to combustion, so emissions are negligible
- Current IGCC design studies with SCR plan ~3 ppmv each of SO_X and NO_X
- Mercury can be removed from syngas at >90% by absorption on activated carbon bed
- By-product slag is vitreous and inert and often salable
- Water use is ~ 70% of a conventional coal plant
- CO_2 under pressure takes less energy to remove than from PC flue gas at atmospheric pressure (Gas volume is <1% of flue gas from same MW-size PC)

IGCC Status, Markets, and Vendors

- 4 single-train coal-based IGCC 250–300 MW (+ 2 others)
- Main needs are capital cost reduction and availability improvement; federal Energy Bill contains incentives
- AEP, Energy Northwest, and Cinergy plan ~600 MW plants. Several others are in development including co-production (ammonia, synthetic natural gas, liquid fuels)
- Technology needs improvement for low-rank coals (the predominant type in the West)
- Worldwide market for IGCC based on petroleum residuals supplying power, steam, and hydrogen to refineries. 8 IGCC plants operating on petroleum residuals (including two multi-train 550 MW plants in Italy). Potential for southern California refinery replacement H_2 co-product?
- Vendor teams (for coal and pet coke): GE/Bechtel, ConocoPhillips/ Fluor/Siemens, Shell/Uhde/Black & Veatch. Possibly others in development (Southern/KBR, Future Energy?)

EPRI Economic Estimates for IGCC & PC Plants without CO_2 Capture—500 MW with Low-Rank Coals (2002–03)

Technology	IGCC E Gas	IGCC Shell No Spare/ Spare	PC Sub	IGCC E Gas	PC Sub
Coal	Wyo. PRB	Wyo. PRB	Wyo. PRB	Lignite	Lignite
TPC $/kW	1640	1480/1690	1330	1830	1340
Coal Cost $/MBtu HHV	1.0	1.0	1.0	0.5	0.5
COE $/MWh at 80% Capacity Factor	54	48/54	44	55	43

Processes for CO_2 Capture

- Current post-combustion process: MEA (amine) scrubbing—absorption plus thermal stripping using energy
- Future improvements for post-combustion: DOE has major programs (EPRI considering major pilot efforts)
  - Improved solvents with lower energy use
  - Novel processes (enzyme, mineralization, ammonia)
  - Novel contacting equipment (membranes, pressure swing, etc.)
  - Improved design of processes and integration
- Alternatives
  - Oxy-fuel (make almost pure CO_2; dry and compress)
  - Gasification plus water-shift and separation of CO_2

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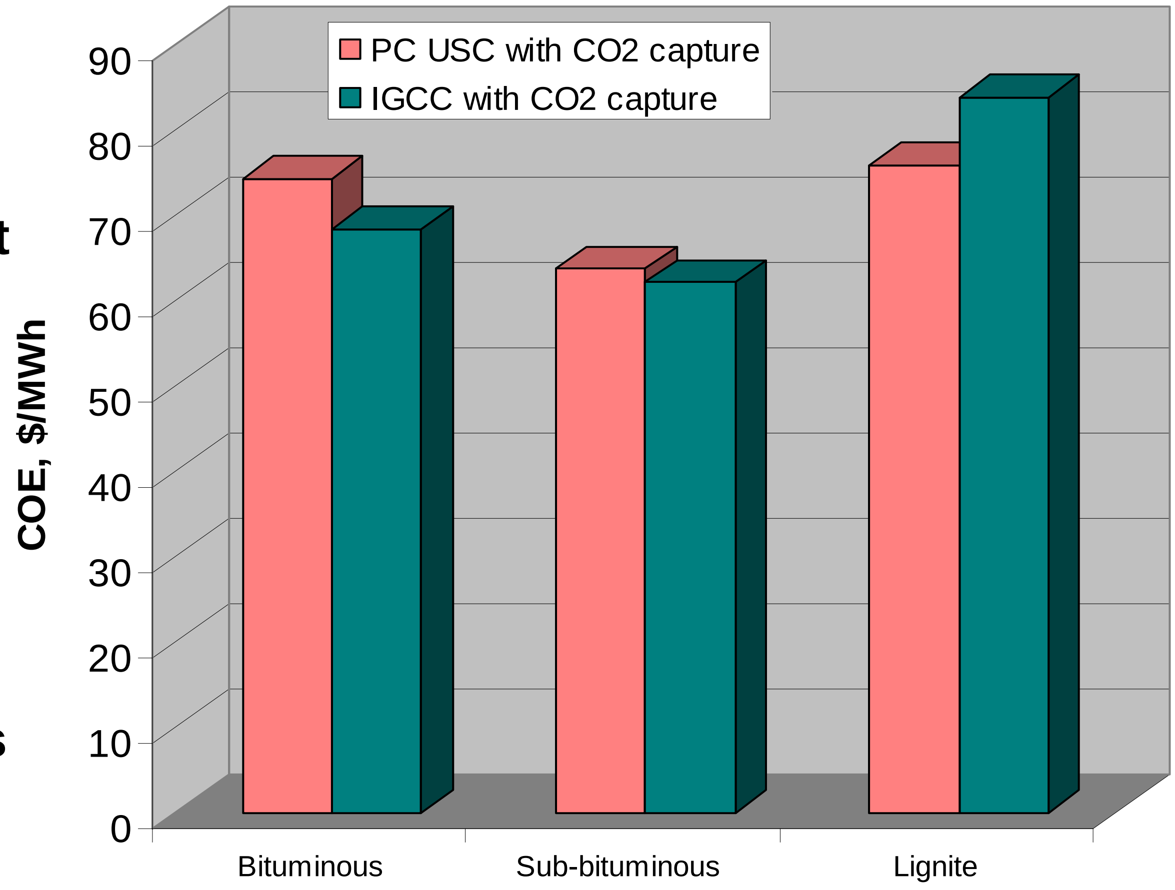
Fuel Impact on PC vs. IGCC Cost of Electricity: Canadian Study Results

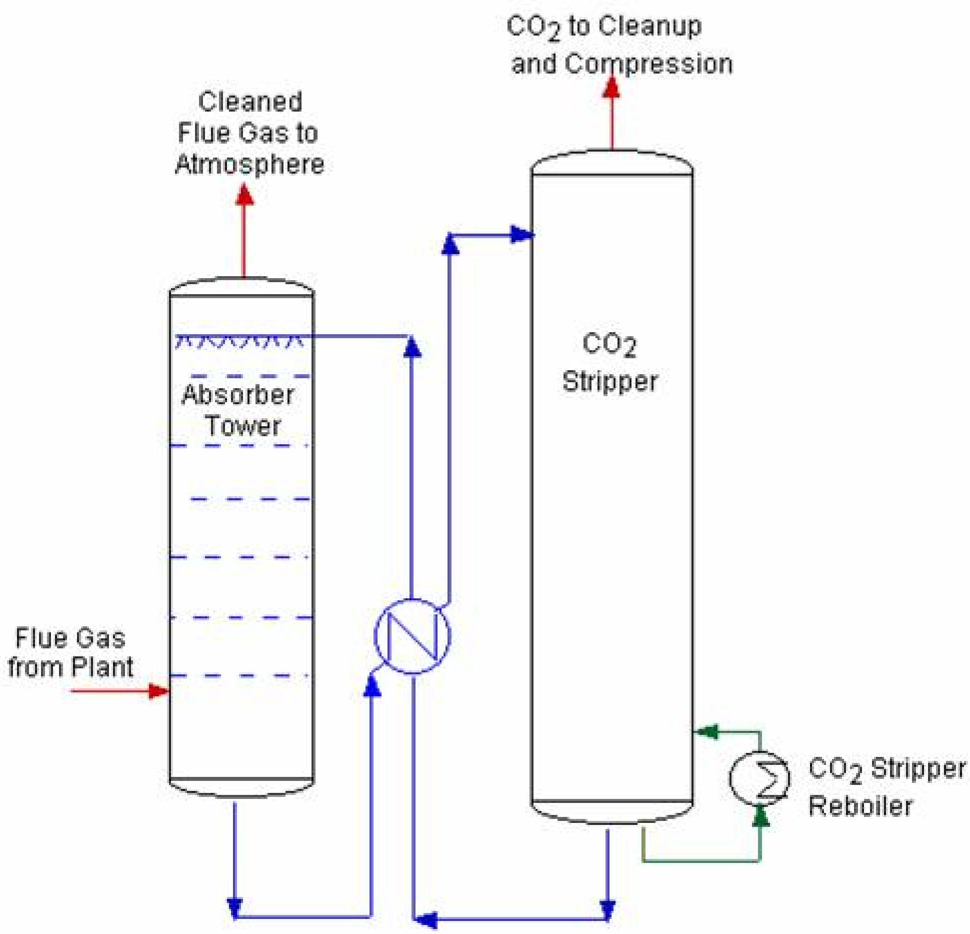
- **PC: Higher cost than IGCC except for lignite**
- **Suggests that fuel choice may have an impact on technology selection**
- **Suppliers addressing the issue**
- **Canadian studies ongoing re-analysis**



Note: Coal Cost—Bit=$1.92/MBtu, SB=$0.48/MBtu, L=$0.845/MBtu; 90% Cap Factor;

CO_2 removal—IGCC 86-89%, PC 95%

CO_2 Capture by Chemical Absorption (Post-Combustion)



- Amine type processes are commercially available (Fluor, Kerr McGee, MHI) and have been demonstrated at 300 mt/day CO_2 (500 MW PC produces ~10,000 mt/day CO_2)
- Requires extensive flue gas pretreatment
  - » Essentially no NO_x or SO_2
- Large reboiler steam requirement
  - » Large reduction in net output
  - » Make-up power source for retrofit of existing plant?
- Looking at options for reduced steam consumption

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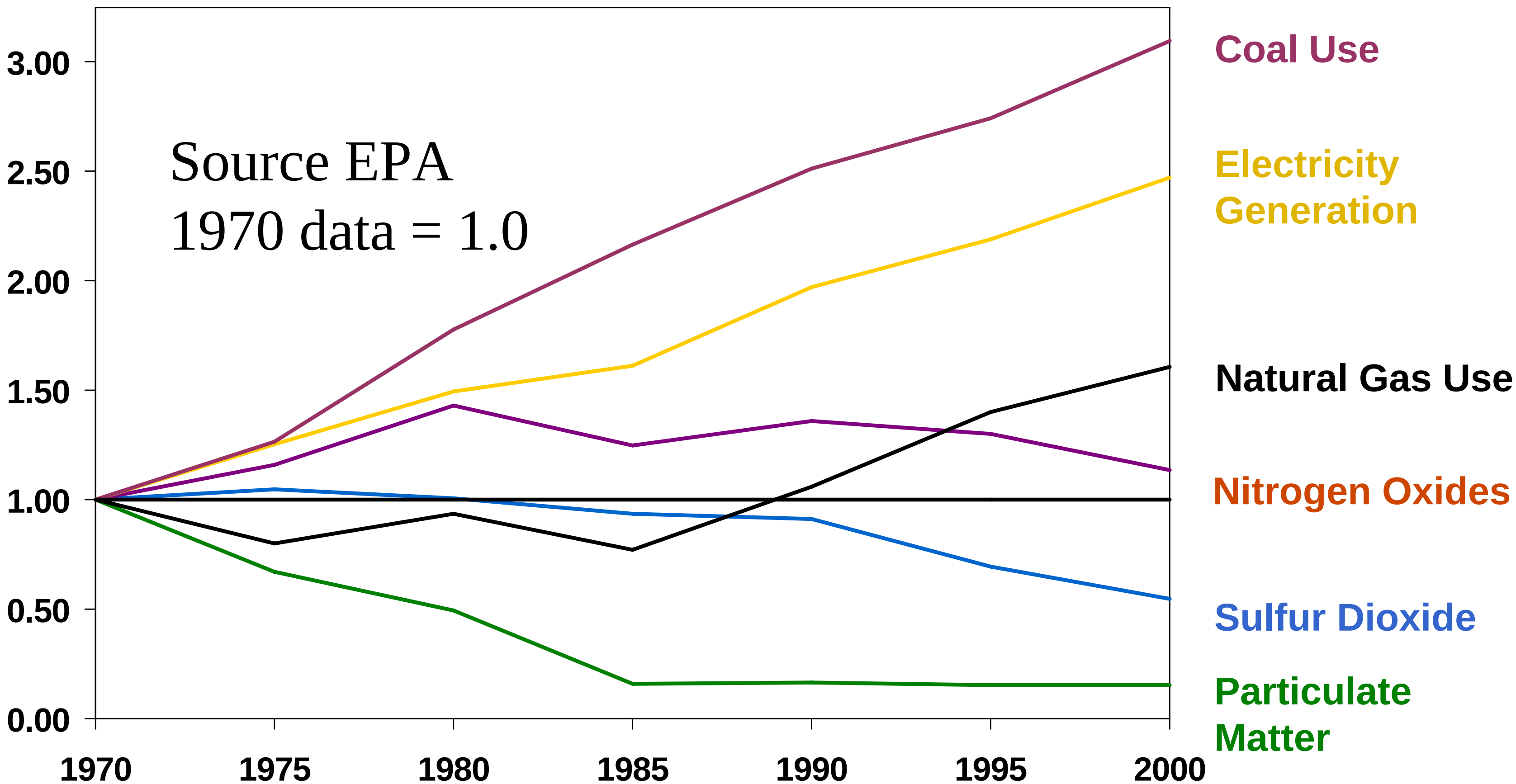
IGCC—Pre-Engineering for CO_2 Capture

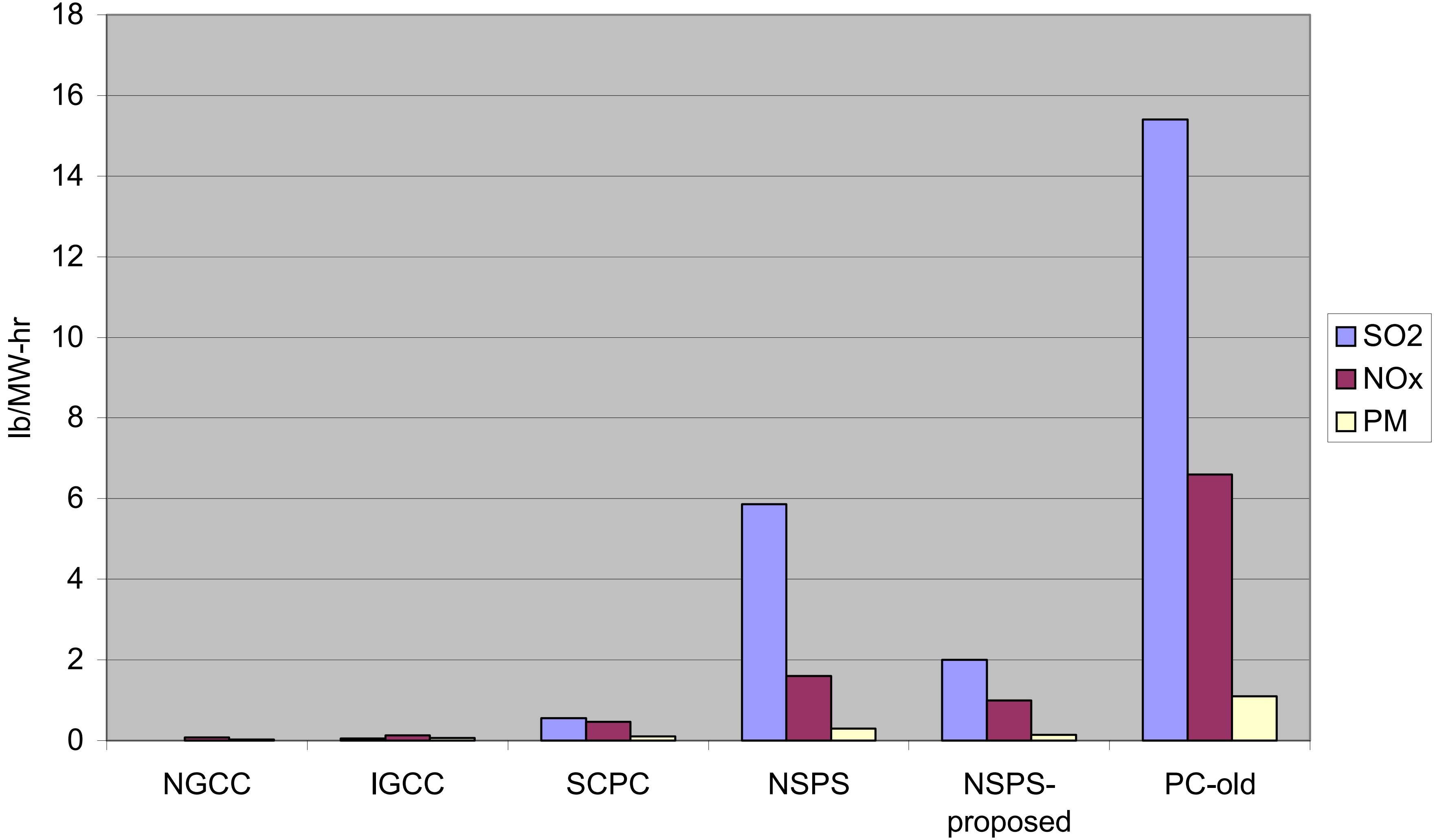
- Converting an IGCC plant to capture CO_2 will take less energy and equipment than a pulverized coal plant, but it is not trivial—it is **not** just "pre-engineering to leave space"
- Gasifiers and Air Separation Units would have to be oversized to match later CO_2 removal (more syngas is needed)
- More moisture is needed to "shift" CO in syngas to CO_2, so different gasifier designs (e.g., quench) may be favored
- Pure hydrogen turbines have not been run at large scale
- Newest "FB" class turbines have not run commercially on syngas, and earlier GE gas turbines have a mismatch on torque limits—new blading may be needed on "FA" turbines, firing temperature derates?
- New burners may be needed as lean pre-mixed low-NO_X burners are not suitable for H_2; N_2 may need to be injected
- EPRI estimates from 2003 Parsons study—it may cost \$30/kW to save \$50/kW later, and the present value may not be there
- More work is needed

U.S. Electric Generation, Fuel Use, and Emission Trends



EPA, National Air Quality and Emissions Trends Report, 1999 (March 2001)
DOE, EIA Annual Energy Review

Emissions Comparison with Older Coal Plants and Federal Standards (Bituminous Coal)



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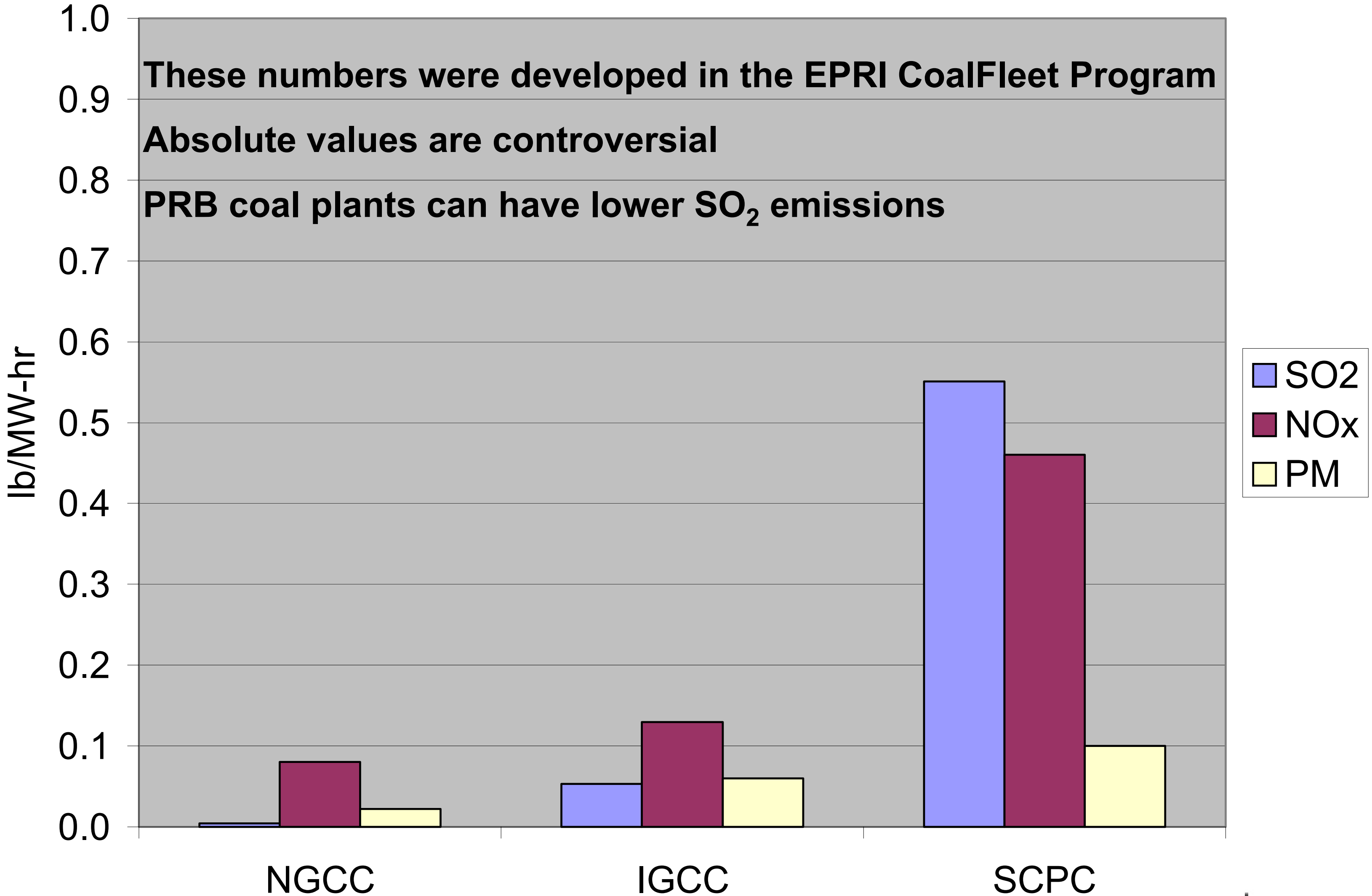
Emissions Comparison: State-of-the-Art Super-critical PC vs. IGCC and NGCC (Bituminous Coal)



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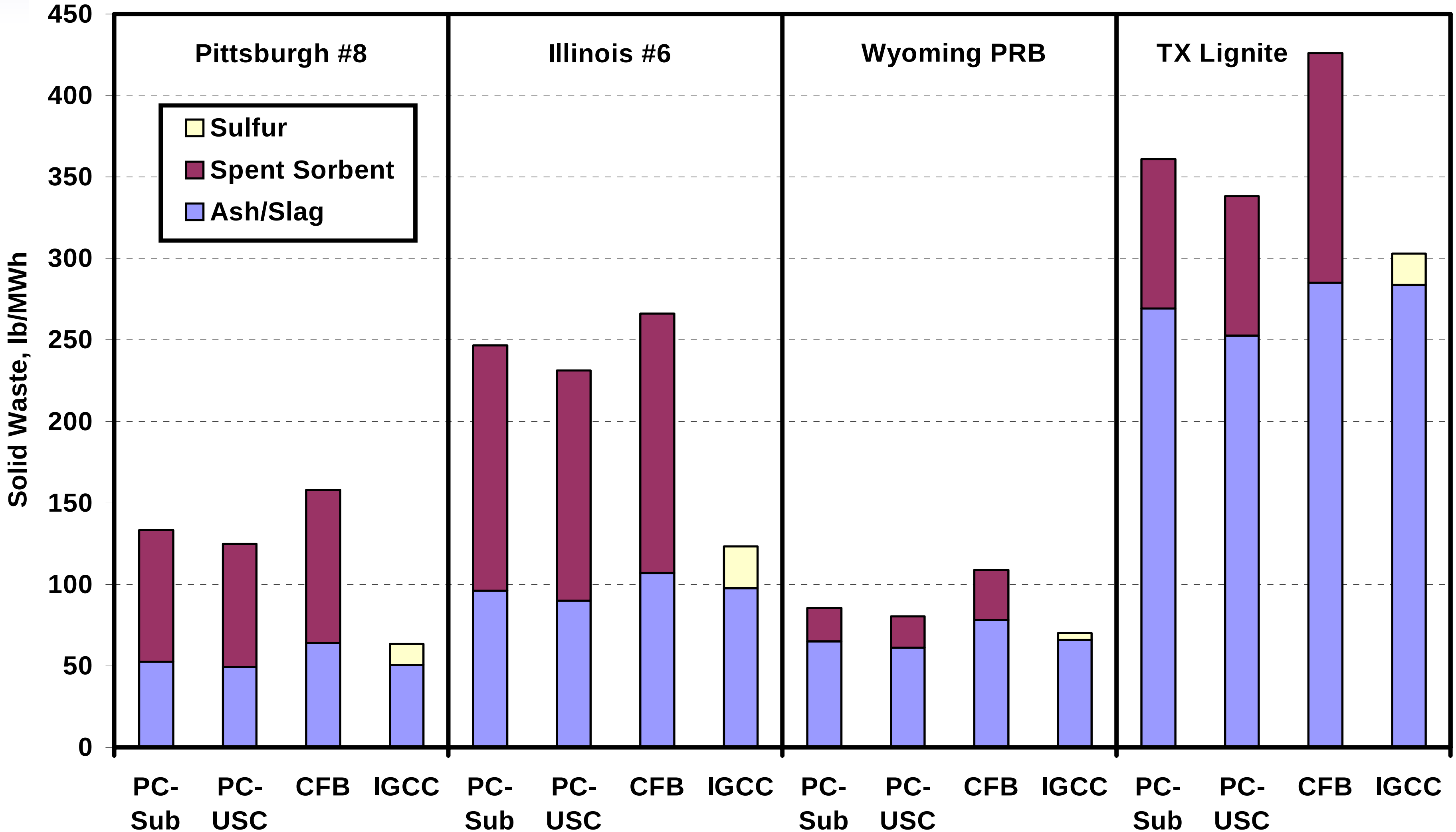
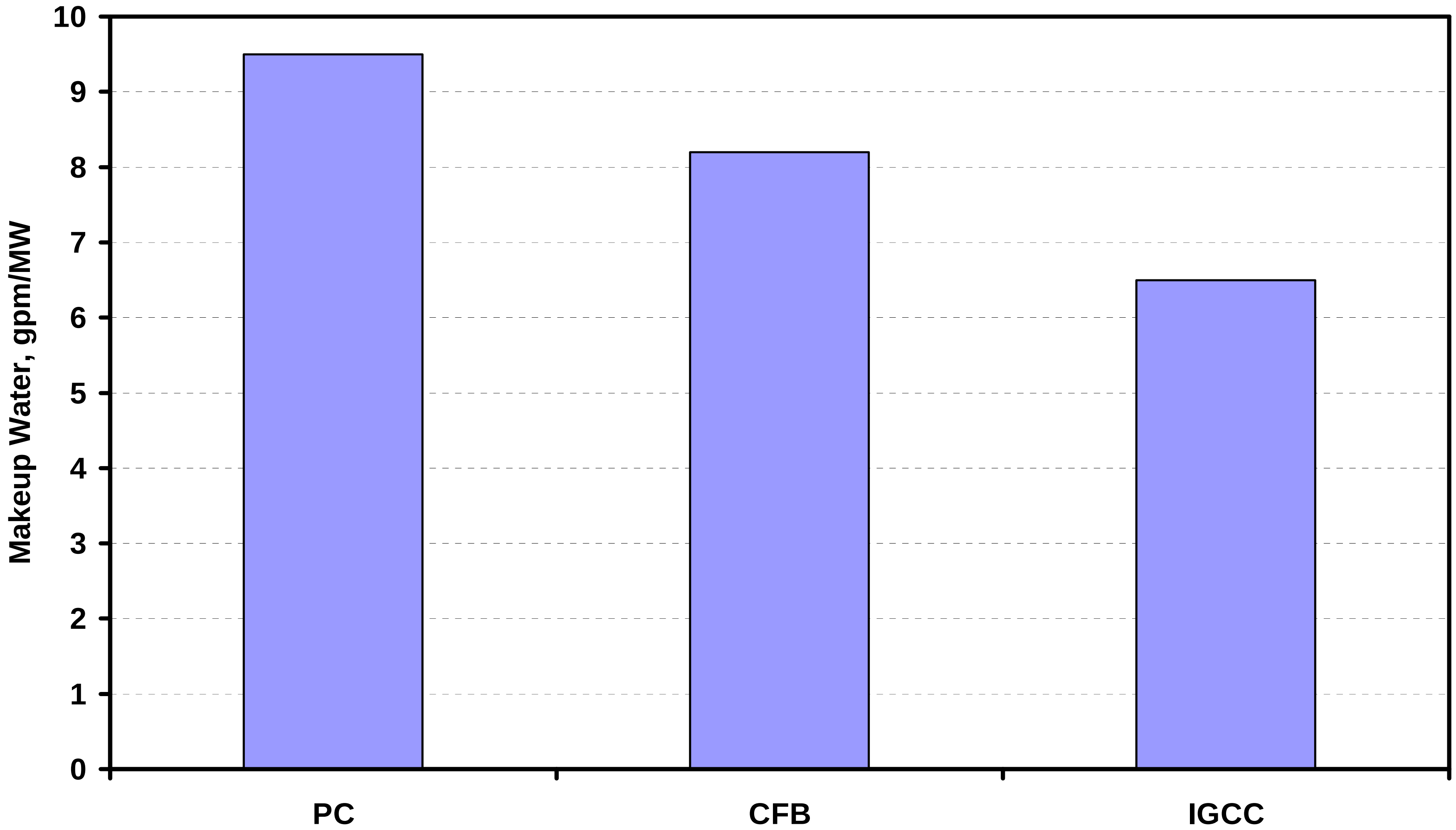
Solid Waste Comparison
(Based on nominal 500 MW plant size)



Makeup Water Comparison



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Questions?